Maritime Institute of Technology & Graduate Studies (MITAGS)
Pacific Maritime Institute (PMI)

Preliminary Maneuvering Study

for the Sparrows Point LNG Terminal

in Baltimore, Maryland

Presented By:
The Maritime Institute of Technology
and Graduate Studies (MITAGS)

October 11, 2006

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1. Introduction

The AES Corporation, through its wholly owned subsidiary AES Sparrows Point LNG, LLC (AES), has proposed to develop and construct an import terminal that will receive and offload Liquefied Natural Gas (LNG) tankers at Sparrows Point in Baltimore, Maryland.

The Maritime Institute of Technology and Graduate Studies (MITAGS) conducted a series of Full-Mission Shiphandling simulation sessions on behalf of AES Sparrows Point LNG, LLC. The sessions were held on July 6-7, 2006 and September 5-6, 2006. During this time, MITAGS simulated the proposed navigation channel and provided four hydrodynamic models that would be similar to the current and future LNG vessels calling on the terminal.

The AES team was headed by Mr. Majid Yavary, Professional Engineer and Vice President of HPA. Mr. Yavary directed the tests on behalf of AES, with oversight from Mr. Christopher Diez, Director of Engineering at AES, and Mr. Kent Morton, Project Director at AES. The services of Captain Gregory Brooks, President of Towing Solutions, Inc., were also retained for this project. Please note that this report uses the term “AES” to represent this team unless otherwise specified.

The MITAGS participants included Captain Curtis Fitzgerald, Shiphandling Consultant; Mr. Hao Cheong, Director of Simulation Engineering; and Mr. Hong Cheong, Simulation Engineer. The services of Dr. Larry Daggett, Professional Engineer and Principal for Waterway Simulation Technology, were also utilized for this project. Please note that this report uses the term “MITAGS” to represent this team unless otherwise specified.

The Maryland Pilots Association participants for this project were Captain John Traut and Captain Kevin Guliotta. Please note that this report uses the term “Pilot” to represent this team unless otherwise specified.

1.1 Background

Figure 1 below depicts the proposed approach channel, shore infrastructure, and surrounding locator map. The proposed terminal project would include the following changes:

- Modification of the existing navigation channel, which is presently known as the “Marine Channel.”

- Construction of a turning area immediately offshore of the existing Sparrows Point Shipyard.

- Modification/replacement of piers to accept LNG vessels.

- Construction of a storage and re-gasification plant in the area between the existing berths (Piers 1 and 2) and graving dock.

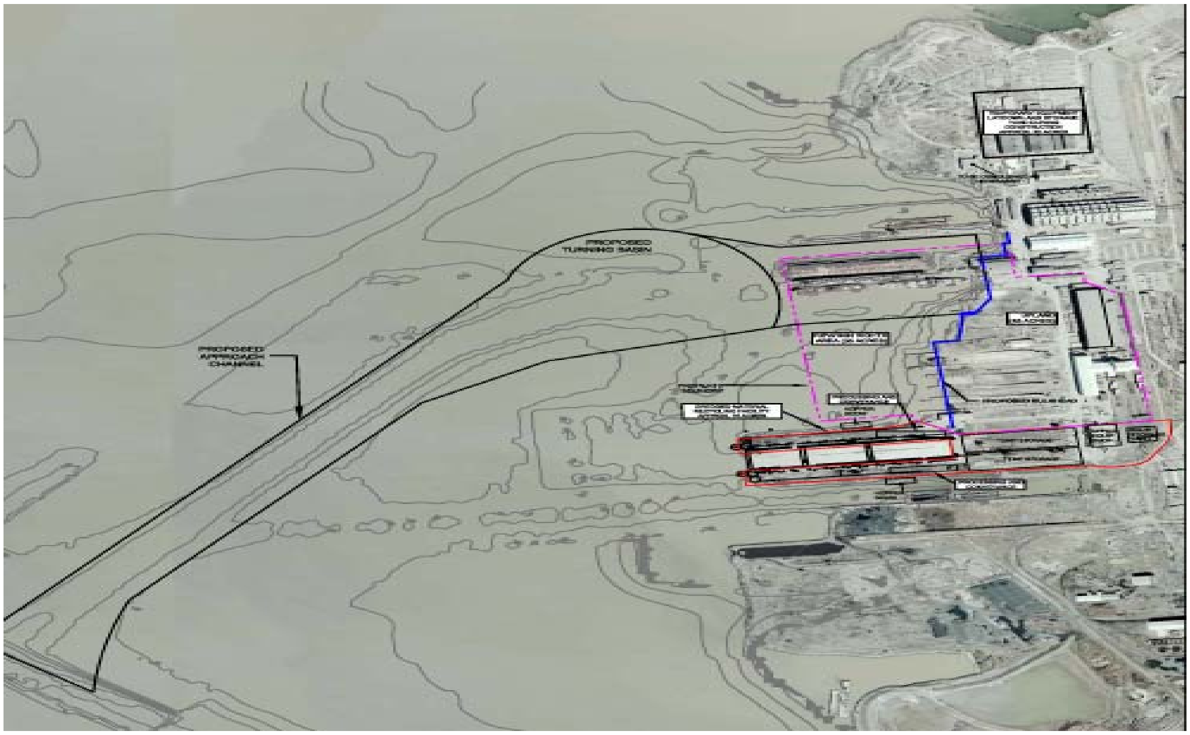

Figure 1

For reference, the initial dredging estimate is depicted in the below-referenced graphic, which is labeled *Figure 2*.

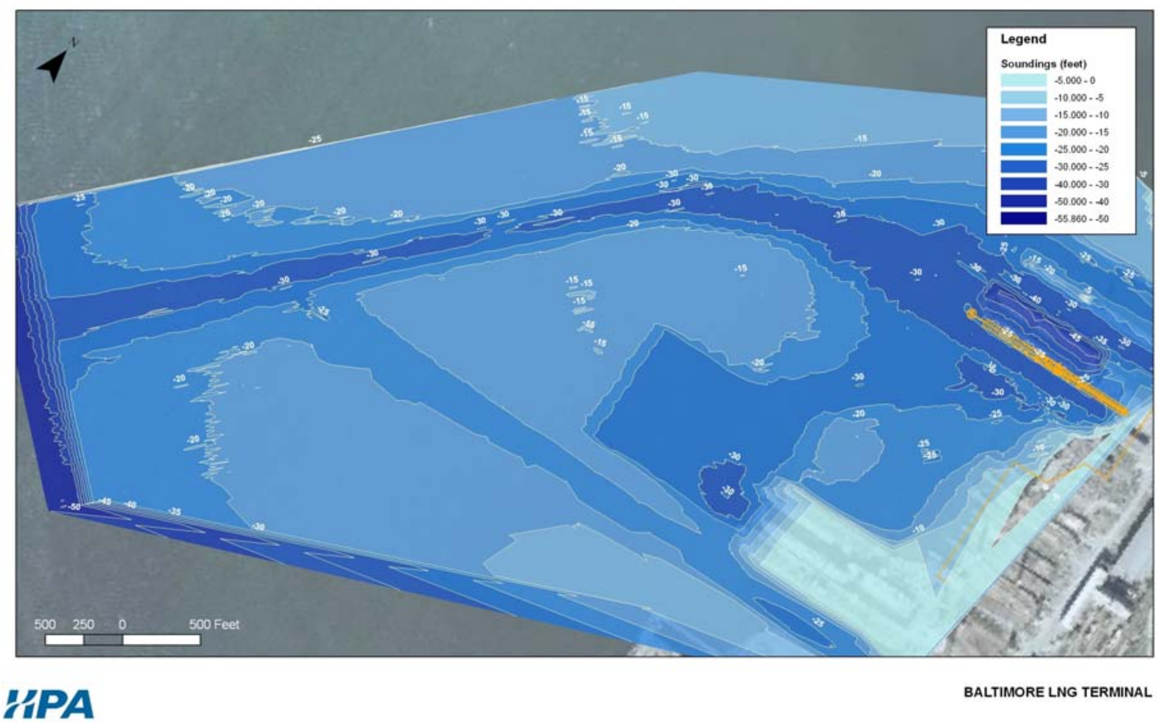

Figure 2

Prior to contracting with MITAGS, AES reviewed the range of LNG transport vessels that are anticipated for use in connection with the terminal project. Such vessels included the existing world fleet of LNG ships and a limited number of larger vessels that are currently in design or under construction. AES determined that use of the proposed terminal by smaller LNG vessels would not be practical due to the following:

- The small and aging fleet of LNG vessels that have a capacity less than 125,000 cubic meters (m^3) are currently dedicated to the existing terminals.

- The vast majority of LNG vessels that are currently on order or being constructed will have a cargo carrying capacity greater than 138,000 m^3.

AES also concluded that use of the proposed terminal by vessels greater than 217,000 m^3 would be unlikely because the few vessels of that size that are under construction will be dedicated to specific terminals. The review further suggested that ships between the 125,000 m^3 and 217,000 m^3 classes will frequent the terminal. Therefore, the MITAGS study considered two different vessels that represented this range of the shipping spectrum.

The first vessel, which was a standard 125,000 m^3 hydrodynamic model (loaded and ballast condition), was used to represent the smaller ships and had the following features:

- 288 meters (945 feet) in length.

- 43 meters (141 feet) in breadth.

- Propulsion modeled after a single propeller, steam turbine.

- Spherical LNG tank system.

Note: this model was already in the MITAGS database library and was based on the "Hoegh Grandia." The model was vetted and used in a number of other studies.

The second vessel used in the study was a 200,000 m^3 "concept" hydrodynamic model (loaded and ballast condition) with the following features:

- 300 meters (984 feet) in length.

- 50 meters (164 feet) in breadth.

- Propulsion modeled after a twin-propeller, slow speed diesel.

- Prismatic LNG tank system.

(Actual sea trial maneuvering data is not available for this size of vessel at this time).

1.2 Purpose

The purpose of the first session, which was held on July 5-6, 2006, was to optimize the dimensions of the navigation channel and turning area to meet permit requirements, minimize dredging, and provide for safe ship maneuvering and ease of transit under a variety of environmental conditions. The secondary objective was to validate the database and verify that the handling characteristics of the LNG hydrodynamic models were realistic. The tests also provided recommendations on the necessary aids-to-navigation to assist in transit and maneuvering activities.

The purpose of the second session, which was held on September 6-7, 2006, was to further test the optimized channel and turning basin design with vessel transits under environmental conditions (wind and currents) near or exceeding expected operational limits. A secondary objective was to further test the placement of the aids-to-navigation and other references to assist in safe navigation of the vessel.

2. Approach

MITAGS programmed the initial channel, turning basin dimensions, and uniform depth of -45 feet Mean Lower Low Water (MLLW) throughout into the Full-Mission Bridge Shiphandling Simulator Number Two (SHS # 2).

AES developed a number of exercises for the Pilot to test. MITAGS programmed these scenarios into the simulator. During the exercises, MITAGS personnel operated the simulator and made necessary adjustments as directed by Pilot. Real-time[1] was used to better simulate the complex decisions and commands that are necessary to perform the stopping, turning, and berthing operations with tug assistance. The use of an area Pilot to conn the simulated ship further infused the exercises with local knowledge and experienced shiphandling skills.

2.1 Shiphandling Simulator

The simulation study used a large-scale, modern, 360° Full-Mission Bridge Shiphandling Simulator, which is shown in *Figure 3*.

The mock-up bridge consisted of an Integrated Bridge System (IBS) with the following components:

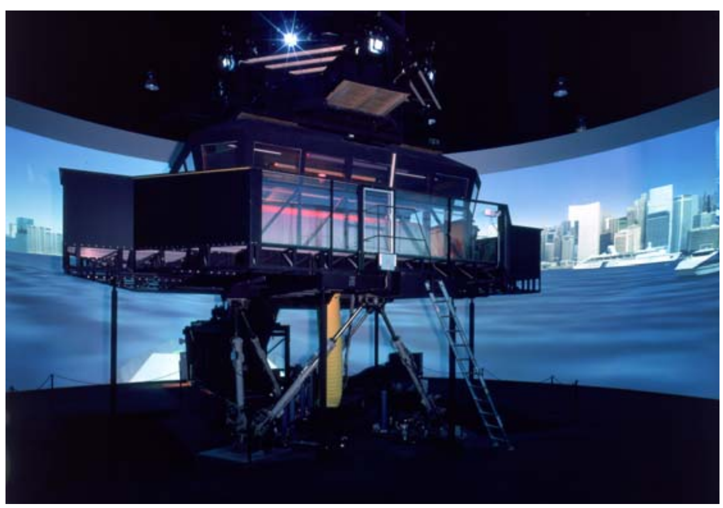

Figure 3

[1] Real time means the time necessary to complete an exercise on the simulator is close to the time it takes to complete the evolution under real-world conditions.

- Electronic Chart Display and Information Systems (ECDIS), which provided the same information as the screen prints on the center console of the bridge.

- Three centimeter (3 cm) radar display.

- Ten centimeter (10 cm) radar display.

Vessel heading, speed, lateral motion, rate-of-rotation, under keel water depth, wind velocity, and wind direction were also displayed in digital readouts. Typical bridge controls were available and operated by the simulator team in response to the Pilot's commands. The vessel models, tug forces, and full integration of the IBS gave participants the perception of working on an actual ship.

The study used four LNG hydrodynamic models (a loaded and ballasted version of each vessel class) to represent the ships listed below in *Figure 4*.

Sparrows Point LNG Terminal
Characteristics of the Proposed Design LNGCs
Rev 2.0 April 14 2006

HPA

Item	Unit	Design Vessels								
		LNGC1	LNGC2	LNGC3	LNGC4	LNGC5	LNGC6	LNGC7	LNGC8	LNGC9
Containment System		S	S	P	P	S	S	P	P	P
Capacity (100%)	m^3	125,000	126,360	126,540	138,059	145,400	165,000	165,000	216,000	217,000
Displacement (summer)	t	101,120	NA	NA	107,000	106,000 (1)	NA	120,000 (1)	145,000 (1)	148,700 (1)
Displacement (ballast)	t	NA	NA	NA	100,000 (1)	NA	NA	NA	108,280 (1)	117,000
LOA	m	287.55	293.7	289.2	277.0 (1)	289.50 (1)	333.00 (1)	314.00 (1)	315.00 (1)	315.00 (1)
LBP	m	274.00	281.2	276.2	266.0 (1)	277.00 (1)	319.00 (1)	300.00 (1)	303.00 (1)	303.00 (1)
Beam	m	43.50 (1)	41.60	41.20	43.40 (1)	49.00 (1)	48.20 (1)	48.40 (1)	50.00 (1)	50.00 (1)
Moulded Depth	m	19.32 (1)	25.00	25.90	26.00 (1)	27.00 (1)	27.50 (1)	27.50 (1)	27.00 (1)	27.00 (1)
Loaded Draft	m	11.52 (2)	11.5 (1)	11.9 (1)	12.1 (1)	11.40 (1)	12.30 (1)	11.50 (1)	12.00 (1)	12.00 (1)
Ballast Draft	m	9.60 (2)	11.3 (2)	10.9 (2)	9.4 (1)	9.40 (1)	10.30 (1)	8.90 (1)	9.40 (1)	10.00 (1)
Manifold Offset from Mid-Ship (LOA/2) (+ = Fore)	m	25.19 (2)	18.9 (2)	31.2 (2)	141.8 (1)	12.13 (1)	-10.90 (1)	0.00 (1)	-8.0 (1)	0.00 (2)
Manifold centerline to Flat Hull limit FORWARD	m	38.90 (2)	73.8 (2)	39.0 (2)	57.8 (1)	61.0 (1)	81.7 (1)	85.0 (1)	60.0 (1)	70.0 (1)
Manifold centerline to Flat Hull limit FORWARD	% LOA									
Manifold centerline to Flat Hull limit AFT	m	73.20 (2)	91.2 (2)	97.5 (2)	73.7 (1)	109.0 (1)	53.9 (1)	59.0 (1)	80.0 (1)	76.0 (1)
Manifold centerline to Flat Hull limit AFT	% LOA									
Windage Area (Ballast longitudinal)	M^2	1,420 (2)	1,335 (3)	1,200 (3)	1,272 (2)	NA	NA	NA	1,510 (1)	1,800 (1)
Windage Area (Ballast lateral)	M^2	6,723 (2)	7,650 (3)	6,200 (3)	5,977 (2)	NA	NA	NA	7,427 (1)	8,450 (1)

Note: Gray background indicates future vessels.

Disclaimer

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Figure 4

Two of the models simulated a vessel with a spherical tank containment design and a capacity of 125,000 $m^{3.}$ Other characteristics included:

- 288 meters (945 feet) in length.
- 43 meters (141 feet) in breadth.
- Propelled by a single 39,425 horsepower steam turbine engine.
- Even keel with a draft of 11.5 meters (37.7 feet) and a displacement of 100,700 tons (loaded).
- Draft of 8.8 meters (28.9 feet) forward, 10.2 meters (33.5 feet) aft, and a displacement of 75,390 tons (ballasted).

The other two hydrodynamic models represented a vessel with a membrane tank design containment system and a capacity of 200,000 m^3. Other characteristics included:

- 300 meters (984 feet) in length.
- 50 meters (164 feet) in breadth.
- Propelled by two 20,000 horsepower diesel engines.
- Even keel with a draft of 12.0 meters (39.4 feet) and a displacement of 138,074 tons (loaded).
- Even keel with a draft of 10.0 meters (32.8 feet) and a displacement of 117,000 tons (ballasted).

The study assumed that the vessel would always be under tug escort during their transit of the Marine Channel and/or Turning Basin. Three simulated tug forces were available to represent the forces that can be exerted by a modern escort (tractor) tug. Each tug was deployed on the simulated vessel per instructions from the Pilot. The tug power was varied during the preliminary design tests, starting with 60 metric tons of bollard force and advancing to 90 metric tons during the latter tests. The September tests limited the tug forces to a maximum of 70 metric tons of bollard pull.

2.1.1 Navigation Channel

Generally, the bathymetric contours and depth data are directly extracted from the electronic charts to aid in the calculation of ship sinkage and grounding. However; in this case, the channel did not yet exist. Therefore, the study used a uniform channel depth of 45 feet below Mean Lower Low Water (MLLW). The Brewerton Channel depths came from the current ECDIS charts.

The study did not simulate “bank effect” since the final shape of the channel has not been determined. However, given the very low speed of the vessel during the simulation runs, the bank effects would have been minimal. The uniform depth extended to the programmed channel boundaries. The ECDIS displayed the vessel’s position in relation to the edge of channel.

The visual scenes included the generic images of the existing and proposed navigational aids. The visual also included a limited number of shore structures and piers. These visual cues assist the Pilot in judging position and motion during channel transits. No visual images of the proposed terminal were included.

2.1.2 Visual and Related Database Sources

The Baltimore database was made up of visual/radar imagery and electronic charts (ECDIS). It was based on NOAA Chart US5MD11M, NOAA Chart US5MD12M, and S-57 formatted electronic chart data for the same area. The S-57 data ensures that the navigational aids, shoals, underwater topography, shallows, and coastline are accurately and consistently located in the visual/radar imagery and in the ECDIS displays.

2.1.3 Aids to Navigation

The initial preliminary design simulations re-located the existing buoys to the design channel boundaries. No other fixed aids were included. During the tests, the aids were modified by adding buoys and pseudo-ranges. Placement of these aids was done “on the fly” during the channel optimization process with the aim of identifying the best possible locations. All modifications to the aids were done after consulting with the Pilot.

Prior to the start of the second session; the proposed channel, buoys, and ranges were placed in the simulated visual, radar, and ECDIS databases. The Pilot had access to the ECDIS, which contained the channel and buoy overlays, through the center bridge console screen. During the testing, the ranges were relocated closer to the turning basin to help enhance the visual sensitivity. This was a reflection of the visual clarity of ranges in the simulator visuals, not real-world conditions.

2.1.4 Environmental Conditions–Wind and Current

AES obtained wind data from the Baltimore-Washington International (BWI) Airport in Linthicum, Maryland. BWI, which is located approximately 16 km (10 miles) southwest of the Terminal, is the nearest weather station with 30 years of measured meteorological data (January 1961 to December 1990). The coordinates of the station are N39^{o} 10′ 34″ and W76^{o} 41′ 2″. Wind speed and direction are collected at 47 meters (154.2 feet) above sea level and are averaged over 1-hour intervals.

Prior to a statistical analysis, the wind data required corrections for height of observation and for surface roughness associated with overland measurements. Following U.S. Army Corps of Engineers (SPM, 1984) guidelines, corrections adjusted the data to the standard 10 meter elevations and to over-water measurements. *Table 1* below shows the percentage of frequency of occurrence for wind speed and direction at the BWI Meteorological Station using the 30-year hourly averaged data.

Direction	**Wind Speed (m/s)**							
	0~1.99	**2~3.99**	**4~5.99**	**6~7.99**	**8~9.99**	**10~11.99**	**12~13.99**	**14+**
N	0.01	2.25	2.06	0.97	0.09	0.00	0.00	0.00
NNE	0.00	1.44	1.22	0.47	0.03	0.00	0.00	0.00
NE	0.01	1.98	1.91	0.60	0.02	0.00	0.00	0.00
ENE	0.01	1.93	1.86	0.68	0.05	0.00	0.00	0.00
E	0.01	2.89	2.36	0.61	0.03	0.00	0.00	0.00
ESE	0.01	1.57	0.97	0.16	0.01	0.00	0.00	0.00
SE	0.01	2.06	1.40	0.43	0.02	0.00	0.00	0.00
SSE	0.01	2.18	1.72	0.57	0.04	0.00	0.00	0.00
S	0.02	3.92	2.43	0.73	0.04	0.00	0.00	0.00
SSW	0.01	2.30	1.82	0.95	0.13	0.01	0.00	0.00
SW	0.00	2.74	2.21	1.12	0.14	0.01	0.00	0.00
WSW	0.01	3.15	2.07	0.74	0.07	0.01	0.00	0.00
W	0.02	8.65	4.51	2.49	0.64	0.08	0.01	0.00
WNW	0.01	3.54	3.46	3.63	1.12	0.15	0.01	0.00
NW	0.01	1.54	2.88	2.88	0.60	0.06	0.00	0.00
NNW	0.01	1.15	1.79	1.29	0.17	0.01	0.00	0.00

Table 1

Figure 5 illustrates the statistical analysis in the form of wind rose. Wind direction is given in meteorological convention as "coming from."

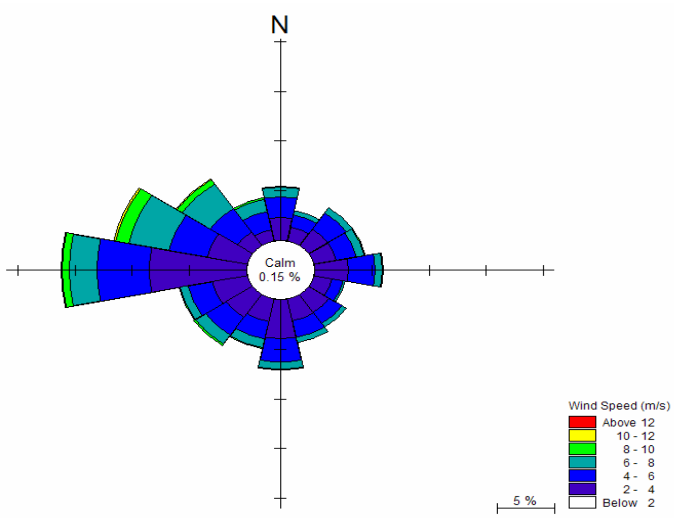


Figure 5

This wind history provided an estimate of the range of wind magnitudes that might be experienced at the proposed terminal. The tests used wind from the direction that would cause the most difficultly in handling the ship. The tests varied wind speed from zero up to the expected operational limit for bringing in LNG ships. The study anticipated that wind would affect the two types of LNG ships differently due to their respective profiles (spherical versus membrane) and displacement.

The study assumed slack water (zero current) for the initial channel optimization tests. The second session used uniform currents, up to a magnitude of 0.25 knots, and applied over the entire channel in an ebb (125° true) and flood (315° true) direction. Although actual current data was not available, it was the general consensus of opinion that these would be the upper level of currents expected in this area.

The second session also ran tests using both current and wind from the most unfavorable direction. This included currents up to 0.25 knots (both ebb and flood) and winds up to 25 knots. Winds in excess of 20 knots are considered the upper range of operational limits.

3. Session # 1 (July 6-7, 2006)–Channel/Turning Basin Optimization

During Session # 1, a number of the exercises and tests were run to determine the optimum channel and basin design. At the request of AES, MITAGS programmed a number of changes to the design and aids-to-navigations. Based on these early tests, an optimized navigation channel/turning basin and associated aids-to-navigation were developed.

3.1 Initial Design

The initial channel design from the preliminary tests, which is shown below as *Figure 6*, included a channel width of 550 feet, with a 950 feet flare at the entrance and a 700 feet flare at the turning basin. It also included a channel depth of - 45 feet MLLW.

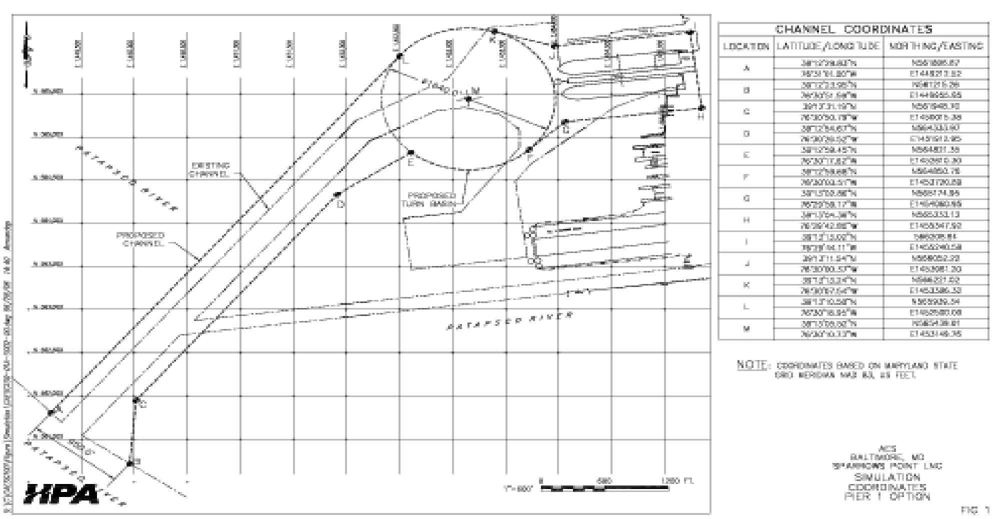


Figure 6

3.2 Optimized Navigation Channel and Turning Basin

The various exercises resulted in the optimized design being tested more thoroughly in Session # 2. The design consisted of a 395 feet wide approach channel, with a flared entrance and 900 feet width at the junction with Brewerton Channel. At the upper end of the approach channel, there was a flare on the southern side of the channel and an 820 feet radius turning basin on the northern side. The turning basin connected to two berths with a minimum of 395 feet between the piers and the channel boundary's. The channel and turning basin water depth was modeled at a uniform - 45 feet MLLW. This layout is shown below in *Figure 7* and is referred to as the optimized channel layout. Since the final pier dimensions are not available, the visual objects inserted within the simulation were approximate in size and

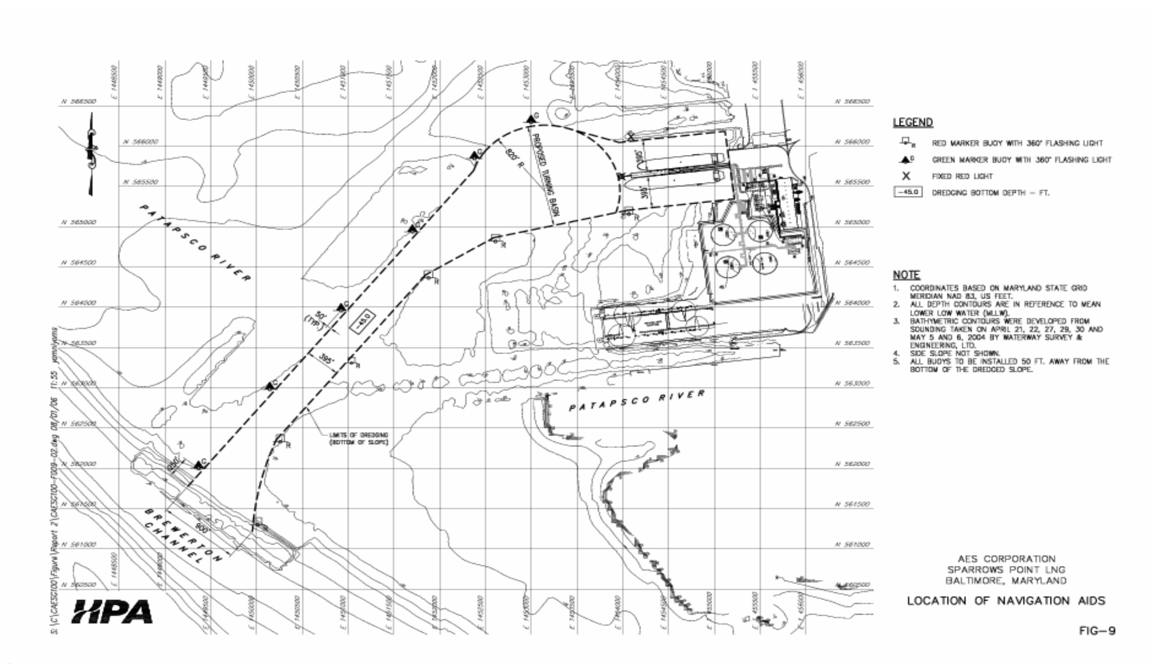


Figure 7

location.

Figure 8 below details the tested buoy locations.

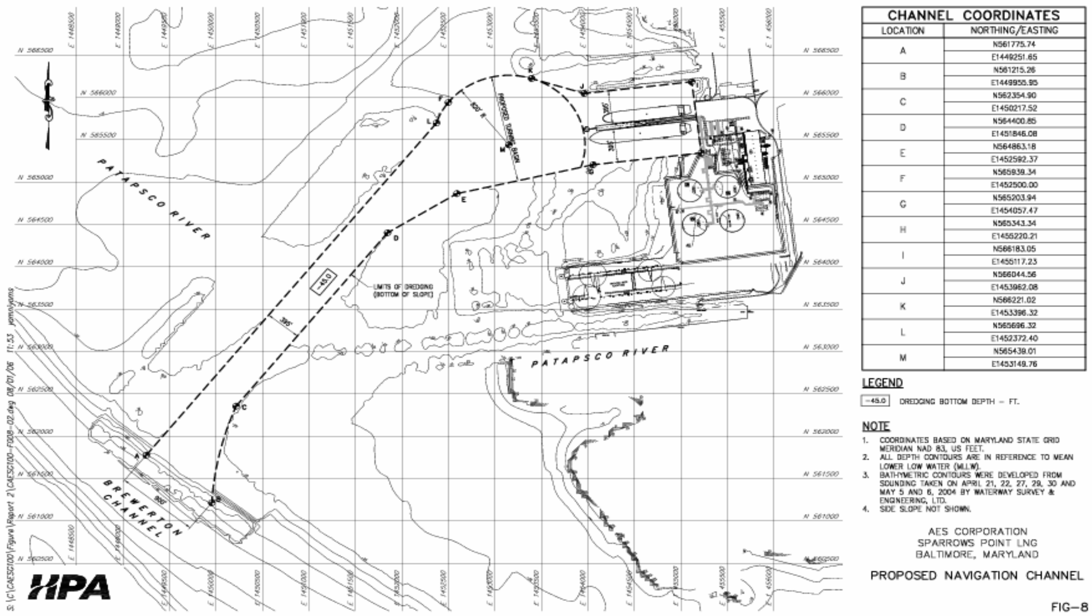


Figure 8

4. Session # 2 (September 5-6, 2006)–Optimized Channel Tests

Session # 2 provided more rigorous testing of the optimized channel design. The two-day session included representatives from AES, HPA, the Maryland Pilots, and MITAGS.

4.1 Track Plots

The following sections provide a number of simulated transits that were performed with the optimized terminal approach channel/turning basin and various environmental conditions. These environmental conditions were generally at their maximum expected operational limit. All of the tests were performed using three 70-metric ton tugs that were positioned as requested directly by the Pilot.

4.2 Figure 9

Ship Size: 125,000 m^3

Condition: Loaded

Current: 0.5 knots at 125 degrees

Wind: 20 knots from 315 degrees

Figure 9 below shows that the Pilot was able to safely transit the channel, enter the turning basin, make a "V" type turn, and back to the pier. While the Pilot came close to the corner of the flare and the northern edge of the turning basin, he had good control at all times. Backing to the pier was difficult for the Pilot due to the visual references. This difficulty resulted in the vessel coming close to the end of the pier. This was not a control problem according to the Pilot. The clearance on the port side of the channel was 150 feet and the wind and current set the ship to starboard. The clearance on the starboard side of the channel was -12 feet due to "clipping" the corner of the flare in the turning basin. Subsequent tests demonstrated that this was probably due to not keeping the ship to the port side of the channel to allow for the set of the wind and current.

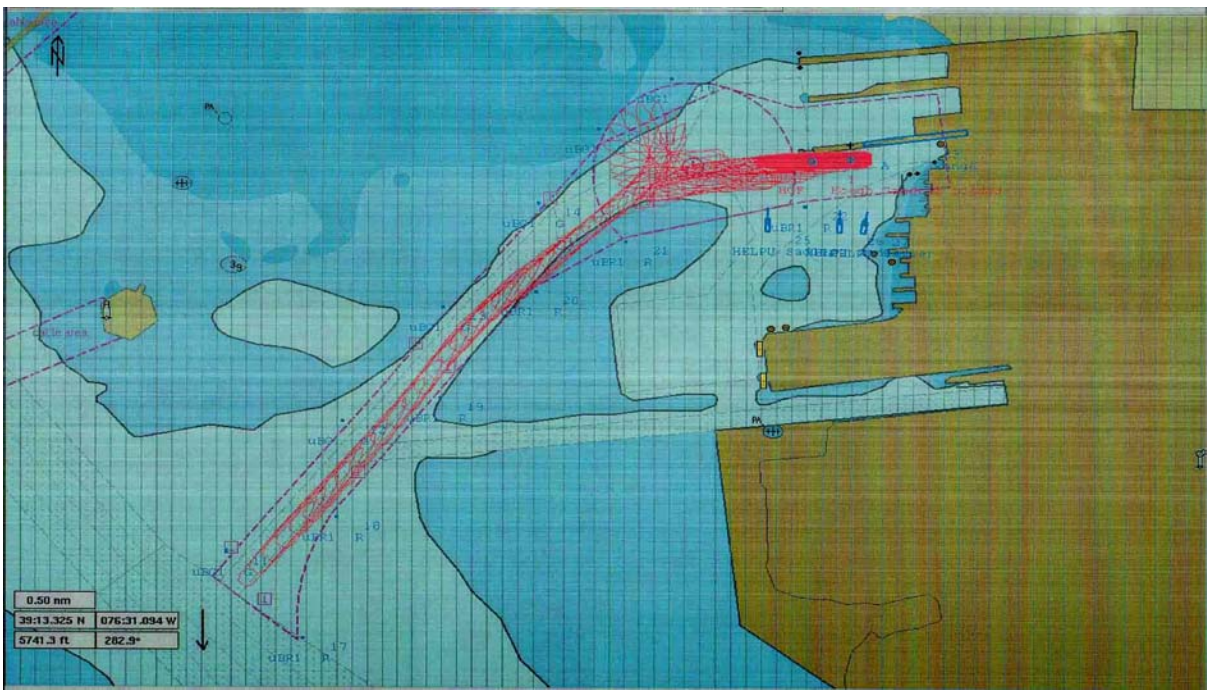


Figure 9

4.3 Figure 10

Ship Size: 125,000 m^3

Condition: Loaded

Current: 0.2 knots at 125 degrees

Wind: 25 knots from 315 degrees

The inbound transit with stronger winds (up to 25 knots from 20 knots) was uneventful as shown below in *Figure 10*. The minimum clearance on the port side of the channel was 34 feet and 58 feet on the south side.

Figure 10

4.4 Figure 11

Ship Size: 200,000 m³

Condition: Loaded

Current: 0.2 knots at 125 degrees

Wind: 25 knots from 315 degrees.

The same conditions were used to bring in the larger 200,000 m^3 LNG vessel in a loaded condition. See *Figure 11* below. Again, the transit was uneventful. The minimum clearance on the port side of the channel was 68 feet and 58 feet on the starboard side.

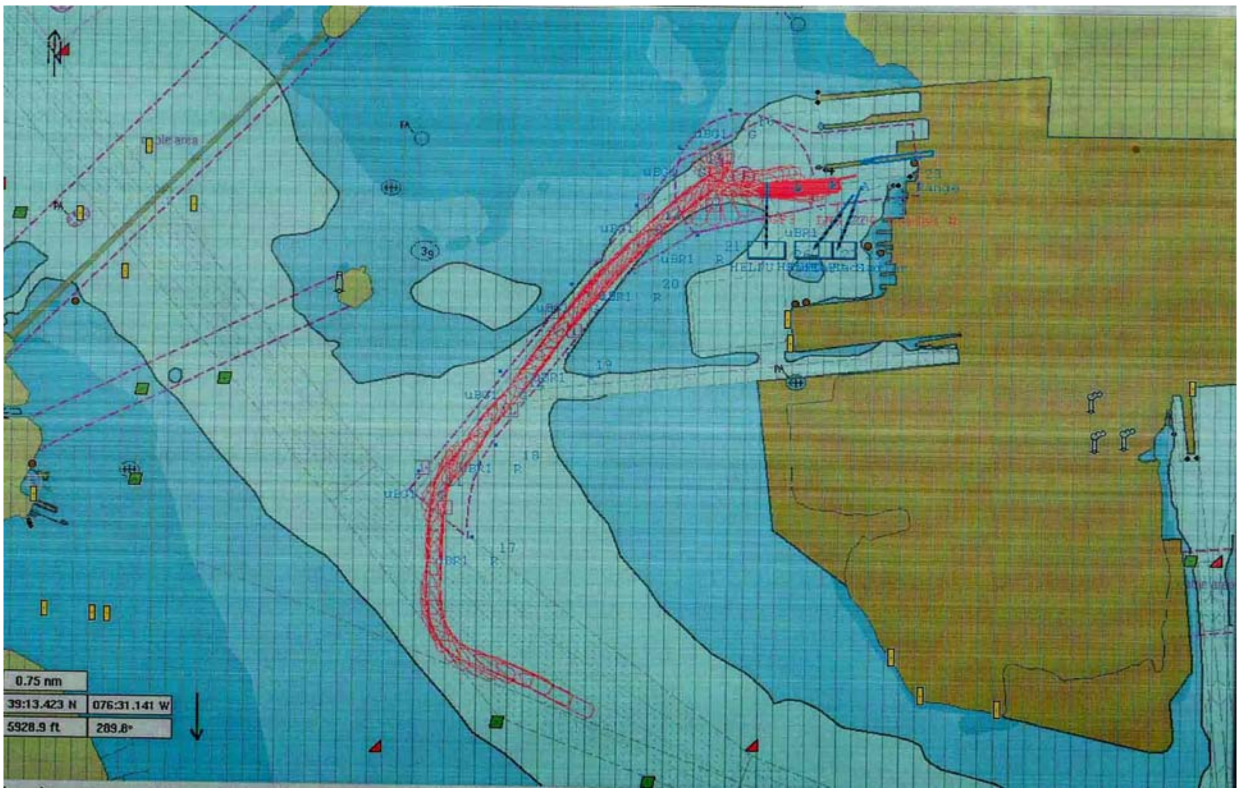


Figure 11

4.5 Figure 12

Ship Size: 200,000 m³

Condition: Loaded

Current: 0.2 knots at 315 degrees

Wind: 20 knots from 125 degrees

With the current, the wind reversed to a flood tide condition with a wind from the southeast. The turn into the navigation channel under these conditions was swept to the port side of the approach channel at the entrance. The ship reached the channel boundary on the starboard side.

Note: this test was re-run due to a computer malfunction.

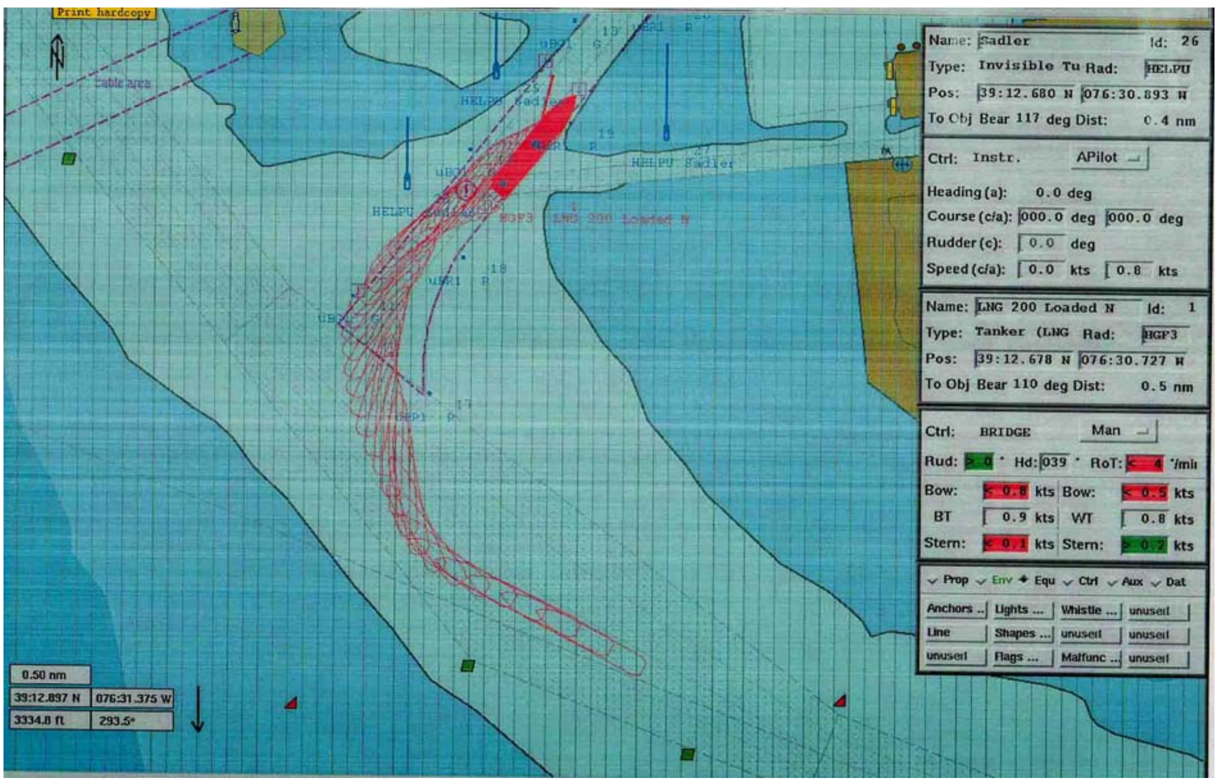


Figure 12

4.6 Figure 13

Ship Size: 200,000 m^3

Condition: Loaded

Current: 0.2 knots at 315 degrees

Wind: 20 knots from 125 degrees

The run was repeated and the transit was uneventful, as the ship was maneuvered to the northern side of the pier. See *Figure 13* below. The clearance on the port side of the channel was 137 feet and 40 feet on the starboard side.

Figure 13

4.7 Figure 14

Ship Size: 200,000 m^3

Condition: Loaded

Current: 0.2 knots at 315 degrees

Wind: 25 knots at 270 degrees

This run was performed with the 200,000 m^3 loaded LNG carrier inbound with flood currents and a westerly wind at 25 knots. See *Figure 14* below. The ship reached the boundary on the port side of the channel. The Pilot reported that the ship was lined up on the ranges and should have been on the centerline of the channel when the ship grounded. The visual ranges were checked and it was determined that the sensitivity of the ranges was not sufficient. The ranges were adjusted and the run was repeated. Since the track pattern was similar to previous runs, the problem of range visibility could also have contributed to the problem experienced in the earlier run.

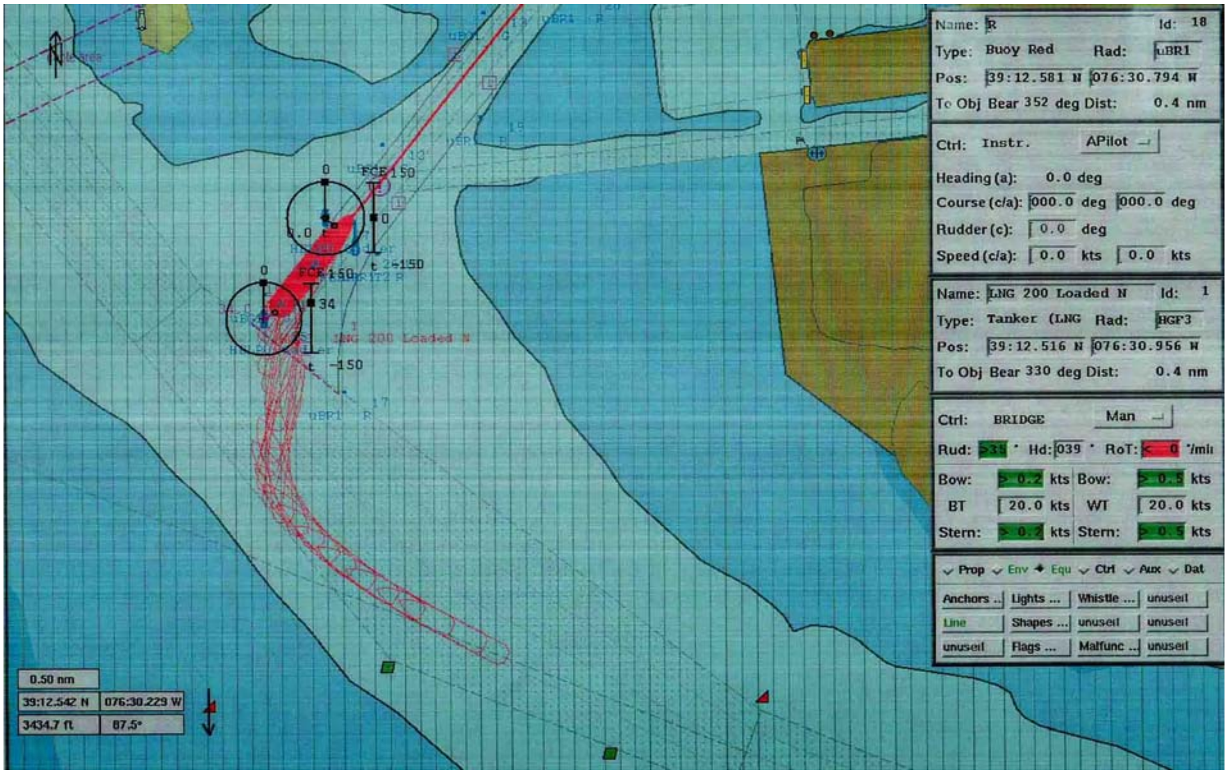


Figure 14

4.8 Figure 15

Ship Size: 200,000 m^3

Condition: Loaded

Current: 0.2 knots at 315 degrees

Wind: 25 knots from 270 degrees.

This run was repeated with the modification to the ranges. The turn into the channel was wide and the ship reached the boundary on the port side of the channel. The ship was brought back into the channel and continued into the turning basin. The turn was made with the ship's bow coming close to the northern edge of the turning basin.

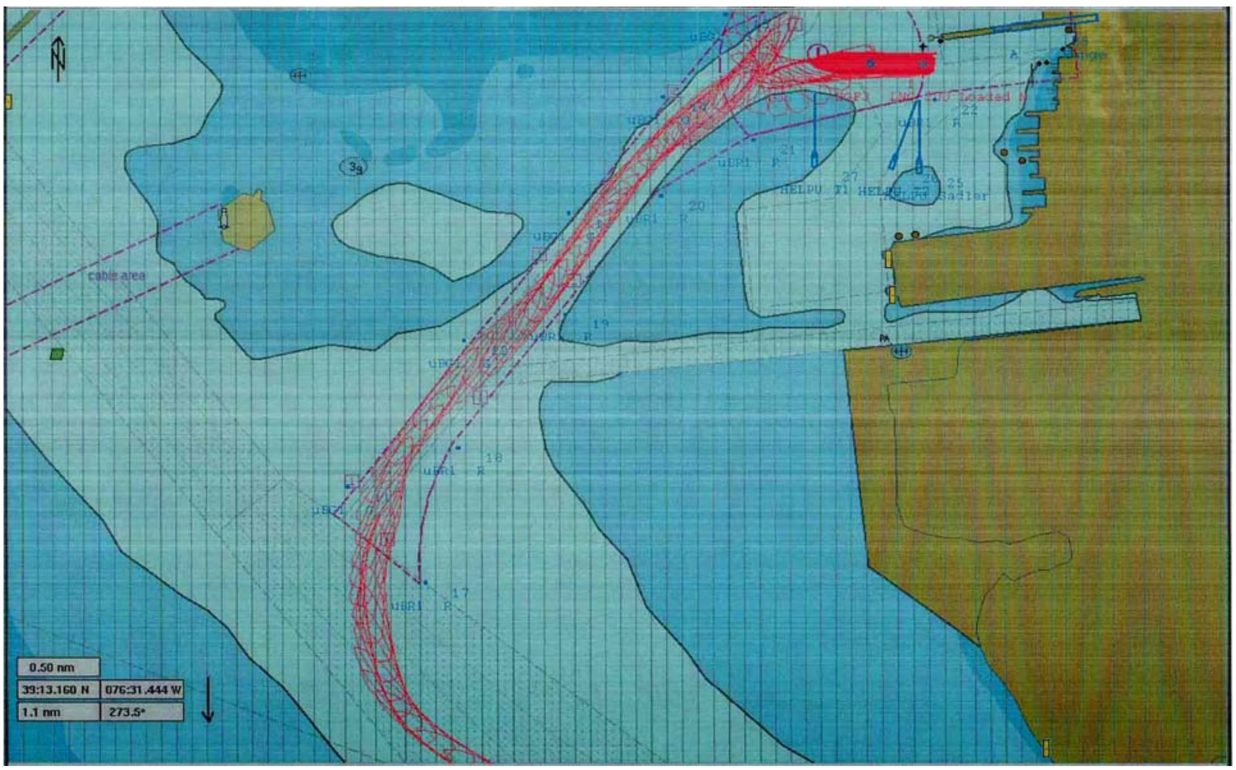


Figure 15

4.9 Figure 16

Ship Size: 125,000 m^3

Condition: Ballast

Current: 0.25 knots at 125 degrees SE

Wind: 25 knots from 315 degrees NW

This test run involved "bringing out" the 125,000 m^3 LNG carrier in ballast from the northern berth, as seen below in *Figure 16*. The tugs pulled the ship off the dock with no problem. The remainder of the transit was uneventful.

Figure 16

4.10 Figure 17

Ship Size: 125,000 m^3

Condition: Loaded

Current: 0.25 knots at 315 degrees NW

Wind: 20 knots from 125 degrees SE

The next test was an emergency maneuver to determine if the three 70-metric ton tugs could control a loaded 125,000 m^3 LNG ship, turn it in the turning basin, and bring it to the dock after losing the engine and rudders in a flood tide with a 20-knots wind from the southeast. See *Figure 17* below.

The run was started in the approach channel with the ship moving at a speed of 2 knots, which was a speed observed in previous transits and agreed to by the Pilot. The tugs were able to get the ship under control, bring it into the turning basin, turn the ship, and bring it to the dock for a starboard docking at the northern berth. The ship's bow did reach the northern edge of the turning basin.

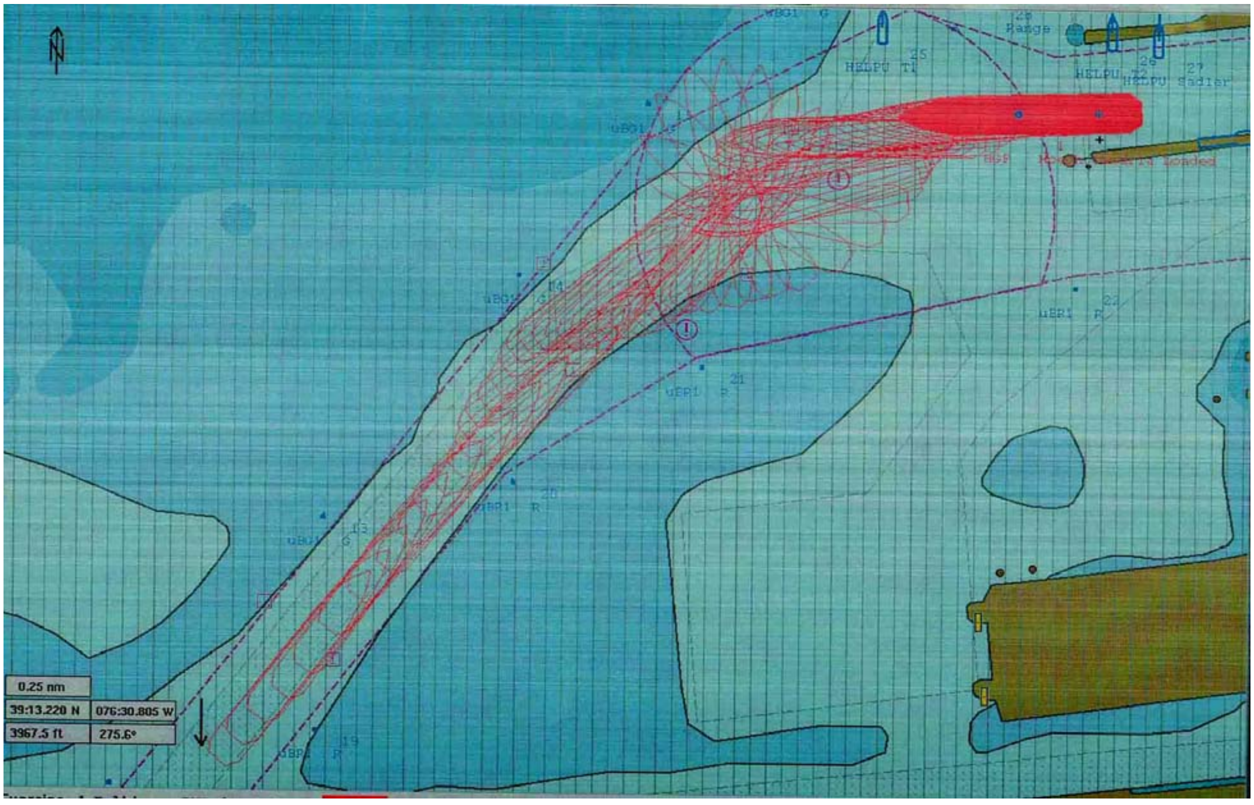


Figure 17

4.11 Figure 18

Ship Size: 200,000 m^3

Condition: Ballast

Current: 0.25 knots at 315 degrees NW

Wind: 20 knots from 125 degrees SE

This transit was a departure of the 200,000 m^3 LNG carrier in ballast from the southern berth with a flood tide and a 20-knots wind from the southeast, which tended to keep the ship on the dock. See *Figure 18* below.

The tugs were able to pull the ship off the dock and, except for approaching the channel boundary on the starboard side, the transit was uneventful. Minimum clearance was 121 feet on the port side and 10 feet on the starboard side.

Figure 18

4.12 Observations

It was observed that in most of the test transits, the ship had a full rudder applied; which held the stern into the wind during most of the transit through the approach channel. The stern tug was then used to keep the ship speed under control and to assist in moving the stern to the position desired by the Pilot (generally near the center of the channel or towards the windward side to allow for setting of the ship across the channel). The two bow tugs were then used to hold the ship's bow in line with the desired transit. The tugs were observed to be generally operated with less than full power most of the time, with bursts of full power to correct an undesired motion.

Most of the test exercises were done with a difficult environmental situation (relatively strong cross currents and cross winds) that enhanced side force on the ship. The strength of the cross current was based on available model data, but was applied as a uniform current all along the channel; which created an unreasonable condition at the northern end of the approach channel. In real life, the shallow water due to the shoals along the upper end of the channel and the shape of the bank line on the eastern side of the bay would create a relatively low current; which would direct the current along the channel axis.

Therefore, the difficulties of handling the ship in the upper end of the channel and in the turning basin would be less severe in the real world. However, the tugs and ship were able to be maneuvered successfully.

4.13 Limitations of the Study and Additional Items to Consider

- When actual or model current information is available, further tests should be considered.

- The underwater shape of the channel was assumed to be a uniform depth of - 45 feet MLLW. Consideration should be given to running additional tests when actual dredge contours are available.

- The simulation visual scenes were limited in that they did not show the proposed terminal. Overlaying the actual and proposed visual scenes would greatly aid the Pilot's "visual depth perception" on the simulator. Consideration should be given to programming the actual visual scenes when terminal design drawings become finalized. Such a database would also be useful for familiarization training of new Pilot's or assist tug crews and for practicing emergency procedures.

- No actual sea-trial data is available for the 200,000 m^3 "concept" LNG vessel. Comparison of handling characteristics ("concept" vessel versus "actual" vessel) should be considered when the data becomes available.

- There were several exercises where the pilot had difficulty in the northern edge of the turning basin near the intersection of the turning circle and the upper western edge of the approach channel. These difficulties are believed to be mainly attributed to the absence of “visual cues” for the pilot in the simulator database. Hence, no design changes are anticipated at this time. Additional visual cues such as the unloading platform on the pier, loading arms, LNG tanks, and other man-made structures will be incorporated into the simulator database for the next set of exercise to confirm this.

- As the design evolves, it will be important to involve more Maryland Pilots to ensure a group consensus on the recommended approach sequence, channel/turning basin design, and final placement of the aids-to-navigation. Additionally, a training program should be established and coordinated with the Pilots to ensure all Pilots are familiar with maneuvers and handling of these ships in accordance with established procedures for the facility.

5. MITAGS Full-Mission Shiphandling Simulator (SHS # 2) Specifications

MITAGS' STN Atlas ANS 5000 simulator employs the latest generation of photo-textured graphics, advanced ship maneuvering capabilities, and a complete Raytheon™ integrated bridge system that utilizes a Kamewa™ joystick and Azipod control systems. The ANS 5000 is a proven worldwide performer in channel design, pier placement research, ship performance testing, wheelhouse ergonomics, and integrated bridge/ship simulation training.

The simulator provides unusually high-fidelity graphics, with precise and accurate ship hydrodynamic behavior. The ships handle with smooth, coupled, realistic motions. Exercise information is used for playback to facilitate lessons learned and modeling data. Visual databases are built from the official S-57, digital terrain and vessel sea trial data, and actual photos of the replicated port. The current library has more than forty ports and forty vessels.

The STN Atlas simulated bridge is housed in one of two unique theaters that are easily the world's largest. The simulator wing has 2 forty feet high, eighty feet in diameter, 360° curved projection screens for the display of large-scale simulation graphics. The complete STN Atlas training system has been constructed to Det Norske Veritas (DNV) "Class A" simulator standards and is configured for one-man bridge operations as defined under the DNV Watch-One certification rules.

5.1 Ownship Model

A sophisticated mathematical model is used to simulate ownship[2] behavior in all circumstances. All necessary parameters and hydrodynamic coefficients are stored in the ownship's database, which serves as a basis for calculation of the ownship dynamics and navigational characteristics.

Modification of the database allows vessel characteristic adjustment by the user. It also enables a high degree of flexibility, which helps solve a wide range of problems in the fields of training and research.

The precision of the mathematical model has been proven several times in close cooperation with the Hamburg Towing Tank Facility and various other Maritime Colleges. Permanent improvements maintain the model as a modern, state-of-the-art level of hydrodynamic design.

2 "Ownship" means the simulated model conned by the Pilot on the bridge.

The ownship’s motion within the water is determined by continuous computation of the mathematical model for the ownship type that has been selected. The mathematical model is based on the integration of the forces and moments produced by all factors acting on the ship's hull. The mathematical model consists of the following:

- A non-linear differential equation of high order.

- A set of coefficients for the ownship type.

The structure of the mathematical model is designed in such a way that the ship types, each with different design features, can be simulated in the same manner. In fact, each type of ownship varies by having a different parameter; which ultimately defines the ship’s characteristics.

Using the published work of Norrbin, the differential equation system is formulated on the basis of the following:

- Longitudinal force balance on the hull.

- Transverse force balance on the hull.

- Horizontal momentum balance on the hull.

All forces and/or moments cause appropriate accelerations. The double integration of these values gives the momentary position and course of the ownship. The movement of the ship is calculated from the balance of all forces and moments acting on the ship's hull. The resultant forces X and Y, or the momentum N, will depend on the ship's current situation. Accordingly, a non-linear differential equation system of higher order describes the ownship's dynamics. This differential equation system is numerically integrated in steps (Euler-Cauchy) until the track of the ship over ground is determined.

5.2 Ownship Effects Modeling

The ownship model takes the following effects into account:

- Main Propulsion
  - (1) Engine
    - (a) Steam turbines, gas turbines, and diesel/electro engines.
    - (b) RPM for each engine variable between full ahead and full astern.
    - (c) Vibration effect.
  - (2) Propeller
    - (a) Fixed and variable pitch.

- Thrusters
  - (1) Bow thrusters.
  - (2) Stern thrusters.

- Rudder
  - (1) Single twin and four rudders.
  - (2) High lift rudder effects.

- Autopilot.

- Stranding/grounding effect.

- Squat effect.

- Bank interaction effect.

- Passing ship interaction effect.

- Collision interaction effect (ownship to ownship).

- Resilient wharf interaction effect.

- Anchor dropping and dredging effect.

- Lines.

- Berthing lines and winches effect.

- Towing and pushing effect.

- Hull hydrodynamics.
  - (1) Shallow water effect

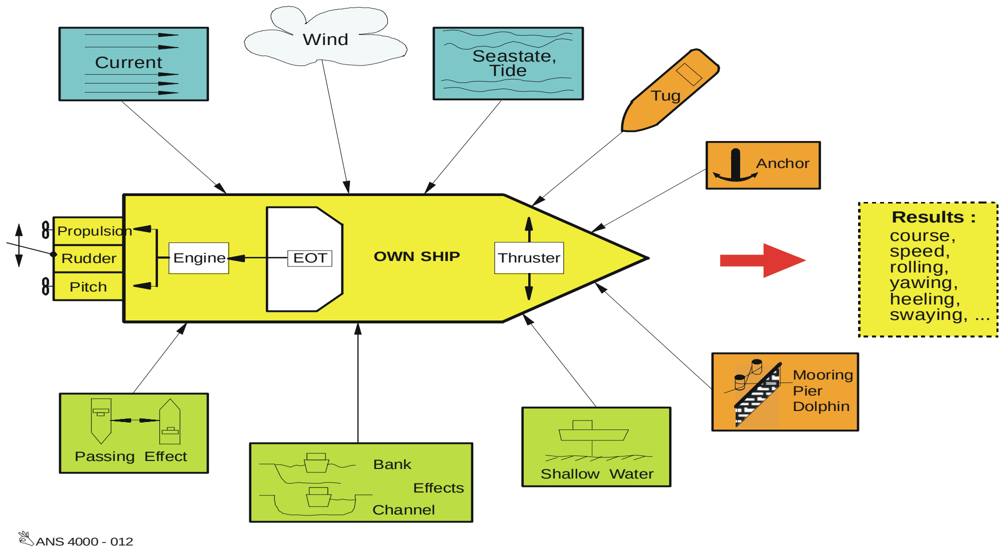


Figure 19

5.3 Hull Forces and Moments

Hull forces and moments are calculated on the basis of hydrodynamic coefficients. Most coefficients depend on water depth, so shallow water effect can be taken into account. The behavior of the ownship then corresponds to the typical behavior of a ship of the appropriate class and size.

Should coefficients be available from model trials, they can be used directly. The balance of all acting forces and/or moments give the resultant acceleration of the ship in the longitudinal, transverse, and turning directions.

Note: trim is also taken into account.

5.4 Main Propulsion

This software routine selectively describes the behaviour of the following:

- Steam turbines.
- Gas turbines.
- Diesel motors.

The propulsion calculation can be carried out using one to four propeller shafts. Fixed or variable pitch propellers can be simulated and the effects of freewheeling propellers are then taken into account. Typical delays of EOT commands are also defined in the database.

5.5 Rudders

There is a provision for single double or a four rudder arrangement. Rudder forces are calculated using the water flow and resistance coefficients. Rudder may be controlled manually or by setting a course command on the autopilot software. Lift and drag are also applied in a four quadrant definition.

5.6 Tugs

Up to eight tugs may support maneuvering of the ownship. The following two types of tugs are currently available:

- Tug of a Traffic Ship - any traffic ship that is controlled by the instructor and used as a tug towing or pushing the ownship.

- Tug of an Ownship - any ownship that is controlled by other trainees that acts as a tug providing a full dynamic interactive simulation.

Ownship tugs may pull or push. A collision detection algorithm prevents the tug from entering into the ownship's contours.

Note: Voith-Schneider propulsion is also selectable in the database.

5.7 Bank Effect

The distance to the bank on either side of the ownship is used to calculate the induced forces and moments that influence the ship's dynamics.

5.8 Wind Forces

Wind forces are calculated using the apparent wind and the appropriate coefficients for the type of ownship. The ownship model can detect inhomogeneous wind forces, which are mainly caused by wind fields. It can also simulate turbulence and wind shields.

5.9 Currents

An inhomogeneous current will cause a drift vector for the ownship's motion across ground. Accordingly, traffic ships change their heading, but follow their given bottom track.

During "automatic current mode," the ownship will measure the current vector at four positions along the hull out of the ECDIS data. This data can be modelled accurately along a river with the tidal sequence (relative to high tide time). The ownship model will turn and move correctly according to the induced hull forces.

5.10 Shallow Water and Squat Effect

The under keel clearance is measured at four positions on the ship's hull using the water depth from the ECDIS and corrected by the tide (relative to high tide time).

Depending on the ratio of draught to under keel water depth, the dynamic coefficients of the hull are interpolated between deep and shallow water data. The turning behavior of the ownship model is then matched to the real turning data.

Note: ownship's with high speeds across a shallow bottom will increase their draught due to the squat effect.

5.11 Grounding
If one of the four depth soundings is less than zero, then the ownship is regarded as having "run aground," where the speed is reduced to zero.

5.12 Coordinate Transformation
After the summation of all hull forces, and the calculation of speed vectors, the coordinate transformations determine the position of the ownship data for correct depth, current, and bank distances.

5.13 Miscellaneous
Miscellaneous routines in the ship model include numerous calculations for the instruments on the bridge (such as depth indicators, log indicators, etc.). The calculation fidelity of the ownship is as follows:

Position Resolution..Better than 10 centimeters
Course Resolution ....Better than 0.1 degrees
Speed Resolution..Better than 0.1 knots
Integration/Calculation Interval ....Configurable; standard 1 S

The ownship motion model supports the following degrees of freedom:

- Lateral direction.
- Longitudinal direction.
- Pitch.
- Roll.
- Yaw.
- Surge.
- Sway.

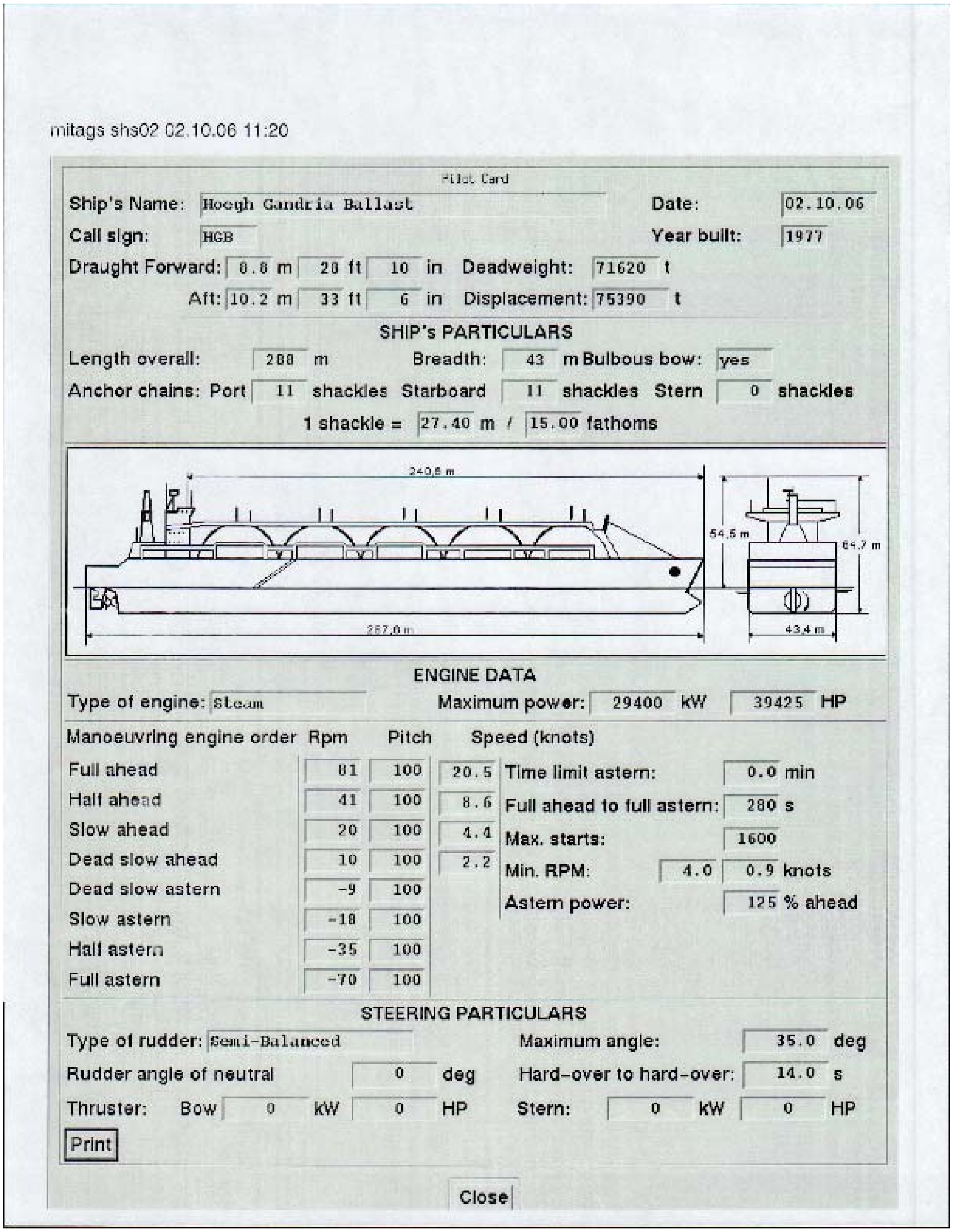
The Ownship limiting values are as follows:

Maximum Speed...> 100 knots
Maximum Rotation.. > 120 degress/minute

6. LNG Ship Models for Maneuvering Simulation Tests

Four ship models were used in the simulation tests. The Pilot Cards for each of these vessels, which describes the principle characteristics that are important to the Pilot when coming onboard the ship, are detailed in the following graphics.

6.1 *"Hoegh Gandria"* Ballast Pilot Card



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Pilot Card

Ship's Name: Hoegh Gandria Ballast Date: 02.10.06

Call sign: HGB Year built: 1977

Draught Forward: 8.8 m 28 ft 10 in Deadweight: 71620 t

Aft: 10.2 m 33 ft 6 in Displacement: 75390 t

SHIP's PARTICULARS

Length overall: 288 m Breadth: 43 m Bulbous bow: yes

Anchor chains: Port 11 shackles Starboard 11 shackles Stern 0 shackles

1 shackle = 27.40 m / 15.00 fathoms

ENGINE DATA

Type of engine: Steam Maximum power: 29400 kW 39425 HP

Manoeuvring engine order	Rpm	Pitch	Speed (knots)
Full ahead	81	100	20.5
Half ahead	41	100	8.6
Slow ahead	20	100	4.4
Dead slow ahead	10	100	2.2
Dead slow astern	-9	100	
Slow astern	-18	100	
Half astern	-35	100	
Full astern	-70	100	

Time limit astern: 0.0 min

Full ahead to full astern: 280 s

Max. starts: 1600

Min. RPM: 4.0 0.9 knots

Astern power: 125 % ahead

STEERING PARTICULARS

Type of rudder: Semi-Balanced Maximum angle: 35.0 deg

Rudder angle of neutral 0 deg Hard-over to hard-over: 14.0 s

Thruster: Bow 0 kW 0 HP Stern: 0 kW 0 HP

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Figure 20

6.2 *“Hoegh Gandria”* Loaded Pilot Card

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Pilot Card

Ship's Name: Hoegh Gandria Loaded — Date: 02.10.06

Call sign: HGF — Year built: 1977

Draught Forward: 11.5 m 37 ft 9 in — Deadweight: 71620 t

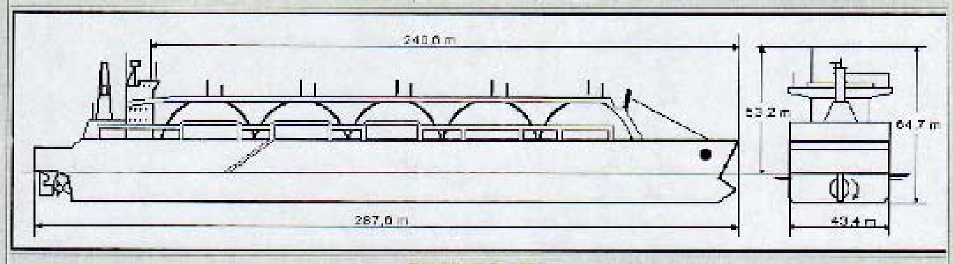
Aft: 11.5 m 37 ft 9 in — Displacement: 100706 t

SHIP's PARTICULARS

Length overall: 288 m — Breadth: 43 m — Bulbous bow: yes

Anchor chains: Port 11 shackles — Starboard 11 shackles — Stern 0 shackles

1 shackle = 27.40 m / 15.00 fathoms



ENGINE DATA

Type of engine: Steam — Maximum power: 29400 kW 39425 HP

Manoeuvring engine order	Rpm	Pitch	Speed (knots)
Full ahead	81	100	19.5
Half ahead	41	100	8.0
Slow ahead	20	100	4.1
Dead slow ahead	10	100	2.0
Dead slow astern	-9	100	
Slow astern	-18	100	
Half astern	-35	100	
Full astern	-70	100	

Time limit astern: 0.0 min

Full ahead to full astern: 280 s

Max. starts: 1600

Min. RPM: 4.0 0.0 knots

Astern power: 125 % ahead

STEERING PARTICULARS

Type of rudder: Semi-Balanced — Maximum angle: 35.0 deg

Rudder angle of neutral 0 deg — Hard-over to hard-over: 14.0 s

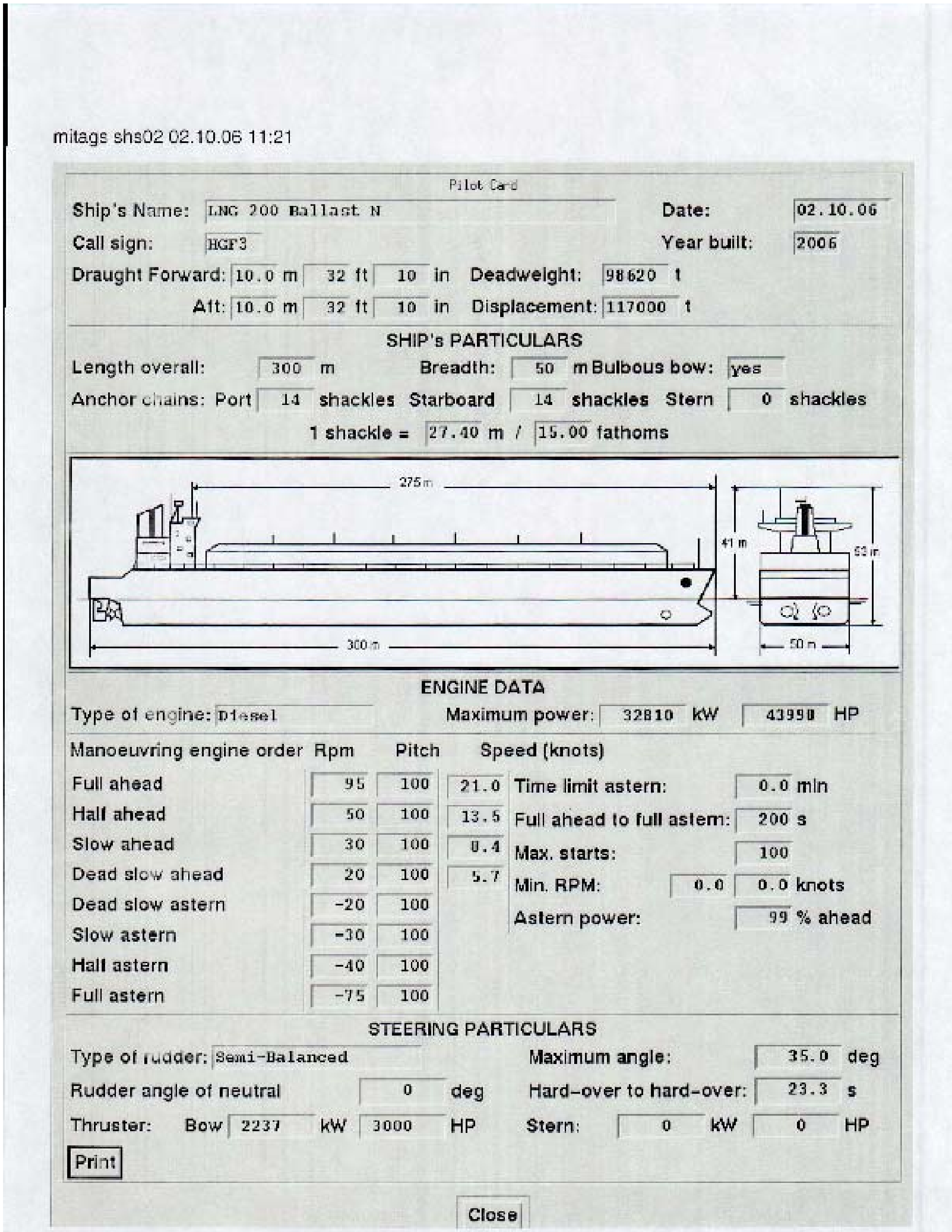
Thruster: Bow 0 kW 0 HP — Stern: 0 kW 0 HP

Print

Close

Figure 21

6.3 LNG 200 Ballast Pilot Card



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Pilot Card

Ship's Name: LNG 200 Ballast N   Date: 02.10.06

Call sign: HGF3   Year built: 2006

Draught Forward: 10.0 m 32 ft 10 in   Deadweight: 98620 t

Aft: 10.0 m 32 ft 10 in   Displacement: 117000 t

SHIP's PARTICULARS

Length overall: 300 m   Breadth: 50 m   Bulbous bow: yes

Anchor chains: Port 14 shackles Starboard 14 shackles Stern 0 shackles

1 shackle = 27.40 m / 15.00 fathoms

ENGINE DATA

Type of engine: Diesel   Maximum power: 32810 kW 43990 HP

Manoeuvring engine order	Rpm	Pitch	Speed (knots)
Full ahead	95	100	21.0
Half ahead	50	100	13.5
Slow ahead	30	100	8.4
Dead slow ahead	20	100	5.7
Dead slow astern	-20	100	
Slow astern	-30	100	
Half astern	-40	100	
Full astern	-75	100	

Time limit astern: 0.0 min

Full ahead to full astern: 200 s

Max. starts: 100

Min. RPM: 0.0 0.0 knots

Astern power: 99 % ahead

STEERING PARTICULARS

Type of rudder: Semi-Balanced   Maximum angle: 35.0 deg

Rudder angle of neutral 0 deg   Hard-over to hard-over: 23.3 s

Thruster: Bow 2237 kW 3000 HP   Stern: 0 kW 0 HP

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Figure 22

6.4 LNG 200 Loaded Pilot Card

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Pilot Card

Ship's Name: LNG 200 Loaded N   Date: 02.10.06

Call sign: BGF3   Year built: 2006

Draught Forward: 12.0 m 39 ft 4 in Deadweight: 98620 t

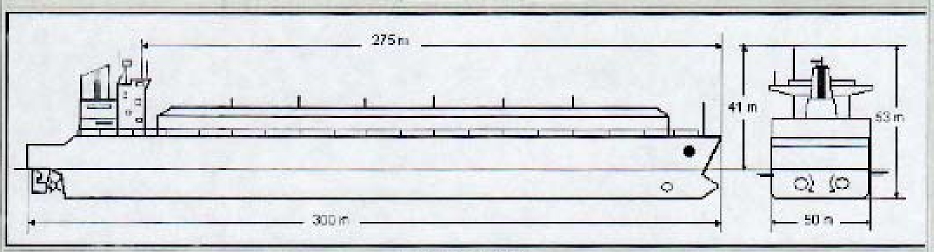
Aft: 12.0 m 39 ft 4 in Displacement: 138074 t

SHIP's PARTICULARS

Length overall: 300 m   Breadth: 50 m   Bulbous bow: yes

Anchor chains: Port 14 shackles Starboard 14 shackles Stern 0 shackles

1 shackle = 27.40 m / 15.00 fathoms



ENGINE DATA

Type of engine: Diesel   Maximum power: 32810 kW 43998 HP

Manoeuvring engine order	Rpm	Pitch	Speed (knots)
Full ahead	95	100	21.0
Half ahead	50	100	13.1
Slow ahead	30	100	8.3
Dead slow ahead	20	100	5.6
Dead slow astern	-20	100	
Slow astern	-30	100	
Half astern	-40	100	
Full astern	-75	100	

Time limit astern: 0.0 min

Full ahead to full astern: 200 s

Max. starts: 100

Min. RPM: 0.0 0.0 knots

Astern power: 99 % ahead

STEERING PARTICULARS

Type of rudder: Semi-Balanced   Maximum angle: 35.0 deg

Rudder angle of neutral 0 deg   Hard-over to hard-over: 23.3 s

Thruster: Bow 2237 kW 3000 HP   Stern: 0 kW 0 HP

Print

Close

Figure 23